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THE PRELOADABLE VECTOR SENSITIVE LATCH FOR ORBITAL DOCKING/BERTHING

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ABSTRACT

This paper describes the workings and function of the "Preloadable Vector Sensitive Latch" designed by Mr. W. R. Acres of NASA JSC. A discussion of docking systems used in U. S. manned space flight programs is included to show how docking systems have evolved, and to highlight the potential advantages of a preloadable vector sensitive latch in such systems.

INTRODUCTION

To fully appreciate the potential advantages of this latching system, it is necessary to understand what has been done in the past relative to docking.

U.S. Manned space flight docking history:

The ability to dock two vehicles in space was first demonstrated during project Gemini in 1966 when Gemini 8 docked with an Agena target vehicle. The docking system in this demonstration is shown in Figure 1. It utilized the rendezvous and recovery section of the capsule to engage a cone interface attached to the Agena. Latching was accomplished by maneuvering an indexing bar located on the capsule nose, into a V-groove on the Agena cone. A latch in the cone then secured the bar in the groove. Release was accomplished by firing reverse thrusters located on the Gemini capsule. The Gemini program proved that rendezvous and docking in space was possible.

In the Apollo program, docking was facilitated by use of a probe and drogue system. This system (see Figure 2) used a probe, located in the command module tunnel, to mate with a cone or drogue, located in the lunar module tunnel. Once the two vehicles were joined with this system, structural latches located radially around the command module tunnel were activated. The probe and drogue were then removed from the tunnel to allow passage from one vehicle to the other. Storing the probe and drogue after removal was difficult due to volumetric constraints.

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Neither the Gemini nor the Apollo docking systems were androgynous. Each vehicle being mated carried a different docking interface. Two Apollo command modules could never dock with each other since both carry only the probe portion of the docking system. This was also true for the Gemini, Agena and Lunar Module since each carried only a male or female portion of a docking system.

One of the prime objectives of Apollo-Soyuz Test Program (ASTP) was to demonstrate the ability of one vehicle to dock with and rescue the crew from another vehicle. To facilitate this, an androgynous system was required. This system (see Figure 3) used three guides attached to a ring in order to correct small angular and translational misalignments. A set of capture latches (protruding thru the guides) was engaged once the two rings made contact. These latches in turn held the rings together until the structural latch system (located radially around the tunnel) could be engaged.

The docking/berthing system concepts currently being studied for Orbiter to Space Station operations are all ring and guide systems. These concepts differ from ASTP by using four docking guides and an attenuation systems on each docking ring as opposed to three guides and an attenuation systems on ASTP. The latching system to be used has not yet been selected. A preloadable vector sensitive latch is one contender for this system.

There are several advantages of a preloadable vector sensitive latch system over the ASTP latching system. One of these advantages is an automatic release feature. If during docking separation, some latches fail to disengage, the remaining latches will automatically release when the ring rotates .14 rad (8 deg) relative to its mating interface. The ASTP structural latch system drove all latches with a cable mechanism. In the event of an inflight failure, manual release of a cable system would be difficult during an EVA while a preloadable latch system would provide easy accessibility. The final advantage of the new latch design is the reduced weight, cost and complexity associated with eliminating one set of latches.

DESCRIPTION

The preloadable vector sensitive latch is an over center locking mechanism which accomplishes both the capture and structural latching of the mating interfaces. As its name implies, it can be preloaded to withstand pressure, moment and seal compression loads being transferred across the mating docking/berthing interface. The loading requirements per latch is 1336 kg (2950 pounds) for docking and 4236 kg (9340 pounds) for worst case Orbiter-to-Station moment loading after docking. Vector sensitivity refers to an automatic latch release that occurs when the vector angle of the applied force on the latch changes significantly.

Each latch is secured in a latch housing located between the primary member and the docking/berthing guide as shown in Figure 4. The latch protrudes thru the guide prior to contact between the two docking vehicles (Figure 4a). During the docking/berthing process, the latch is pushed into its supporting housing within the guide by the front surface of the other vehicles docking interface (Figure 4b). As the latched member moves closer to the primary member, the latch moves around the latched member and finally comes to rest on the 45 degree chamfer along the back side (Figure 4c). Compression loads between the latch and primary members are created by exerting a compression loads on the member chamfer by the latch roller (see Figure 4d). As originally envisioned, there would be eight latches on each member ring, two per guide.

The system consists of three links, one actuator, a bearing surface roller, a sliding pin joint, a housing and a return spring mechanism (see Figure 5). Figure 6 shows the forces acting on the latch system during docking. The force "L2" is a frictional force between the sliding pin and housing caused by resultant force "L1." For this pin to housing interface, a static friction coefficient of 0.1 was assumed. The following equations are used when summing forces and moments on the main link:

(i) $Q = ARCOS ((B^2 + C^2 - A^2)/(2*B*C))$
(ii) $H = ARCOS ((C^2 + A^2 - B^2)/(2*C*A))$
(iii) $I1 = Q - (.785 \text{ RAD} - G) + J = Q - (45 \text{ deg} - G) + J$
(iv) $M1 = M*C*SIN(D) - K*A*SIN(N8)$
(v) $Fx = M*SIN(D) - K*SIN(I1) - L1 + Fs = 0$
(vi) $Fy = K*COS(I1) + L2 - M*COS(D) = 0$
(vii) $L2 <= (0.1*L1)$

Known Variables	Unknown Variables
I1 = release angle	M = yoke force
K = designed latch load	D = yoke angle
Fs = known spring force	L1 = bearing pin force
L2 = pin frictional force	

By assuming values for angle "D" in equation (iv), corresponding values of "M" can be computed. These values when substituted into equation (v) produce values for "L1." Using these values for "D" and "M", the force "L2" can be obtained from equation (vi). To remain latched, the value of "L2" from equation (iv) must be less than or equal to the normal force "L1" times the static friction coefficient equation (vii). Either a decrease in angle "D" or an increase in angle "I1" causes equation (vii) to be violated and the latch automatically releases. (Figure 7)

DEVELOPMENT TESTING

Several variables effect release operation of the latch. These variables include friction within the pinned joints, deviation from the assumed static friction coefficient, and the force imposed by the return spring. To aid in evaluating the effects of these variables, a series of tests has been developed. Results of these tests are intended to prove the following:

(i) The latch will release by rotating the yoke to a given release position (angle "D" is decreased).

(ii) The latch will collapse when contacted at angles greater than the release angle (angle "I1" is increased).

(iii) The latch will withstand the design loads.

(iv) The latch will automatically release when the load angle is rotated .14 rad (8 deg), from -.79 rad (-45 deg) to -.65 rad (-37 deg) (angle "I1" is increased).

(v) The latch can be released while loaded to the design release load by rotating the yoke to the release position.

(vi) Clearance between the latch roller and mating docking ring can be removed and the desired preload can then be applied.

During testing of objective (iii), the latch was to be loaded to 4236 kg (9340 pounds) while measuring deflections on the upper pin joints of the main link. Movement exceeded design limits resulting in rotation of the yoke to the release position. When the applied load reached 4073 kg (8980 pounds), the latch released.

Further testing was conducted until the cause of the premature release could be investigated.

ANALYSIS OF RESULTS

From preliminary analysis of the test results, objectives (i) and (ii) have been achieved. The third objective was also partially achieved.

Objective (i) was proven by loading the latch to approximately 45.3 kg (100 pounds) at a force vector of -.79 rad (-45 deg) as shown in Figure 8. The yoke angle "D" was then decreased until the latch released. The resulting value for "D" was slightly less than the calculated value. Once this angle was established, the latch was set at this angle and loaded to determine the actual force required to collapse the latch. The average value for this force is 36.2 kg (80 pounds). This testing demonstrated the ability of the latch to release when the yoke is rotated to a given release position.

Objective (ii) was demonstrated by loading the mechanism at angles ranging from -.52 rad (-30 deg) to 1.83 rad (105 deg) in .26 rad (15 deg) increments (see Figure 6). The forces required to release the mechanism ranged from 11.3 kg (25 pounds) to 1.8 kg (4 pounds) with higher loadings required in the -.52 rad (-30 deg) to .26 rad (15 deg) and 1.31 rad (75 deg) to 1.83 rad (105 deg) angle ranges and lower loads in the .26 rad (15 deg) to 1.31 rad (75 deg) range. These results demonstrate that the latch will collapse when contacted at angles greater than the release angle.

The ability of the latch to handle the design loads (objective iii) was partially demonstrated by loading the mechanism to 96% of the design load prior to latch release. Inspection of the links indicated no permanent deformation in any memeber. Although the design load was not achieved, the ability of the latch to handle high loading while in the latched position was successfully demonstrated.

Preliminary analysis indicates that premature release of the latching mechanism occurred when the yoke rotated to the release position. This rotation was due to the movement of the main link relative to the fixed yoke position. Potential causes for this relative rotation are:

(i) Movement of the latch housing (relative to the test base) due to bolt hole tolerances.

(ii) Movement of the sliding pin prior to final release.

(iii) Movement of the yoke caused by tolerances in the turnbuckle assembly.

FUTURE TESTING

Tests done to date will be repeated after several changes to the test hardware are completed. These modifications will allow measurement of the sliding pin motion and determination of latch housing movement relative to the base plate. Alterations to the turnbuckle assembly (load application test fixture) will be made to allow more accurate control of yoke movement.

Further tests will be performed to verify testing objectives (iv), (v) and (vi) listed above. The latch will be loaded with the force vector applied at -.79 rad (-45 deg) and release when the latch is rotated .14 rad (8 deg) while under a constant load of 1336 kg (2950 pounds). The latch will then be released by rotating the yoke to its release position with a constant load of 1336 kg (2950 pounds) applied to the roller. The latch will also remove .31 cm (.125 in) of clearance and then be preloaded to 4231 kg (9340 pounds) by applying a relatively small load on the yoke.

CONCLUSION

The concept of a vector sensitive latch has been demonstrated in tests with the property of locking and releasing when loaded at predetermined angles. The ability of preloading this latch to carry structural loads has also been demonstrated. Additional testing is required to prove the clearance removal and preload features of the design.

The potential advantages in reliability, safety, serviceability, weight and cost reduction provided by this latch system offer improvements in future docking/berthing systems.

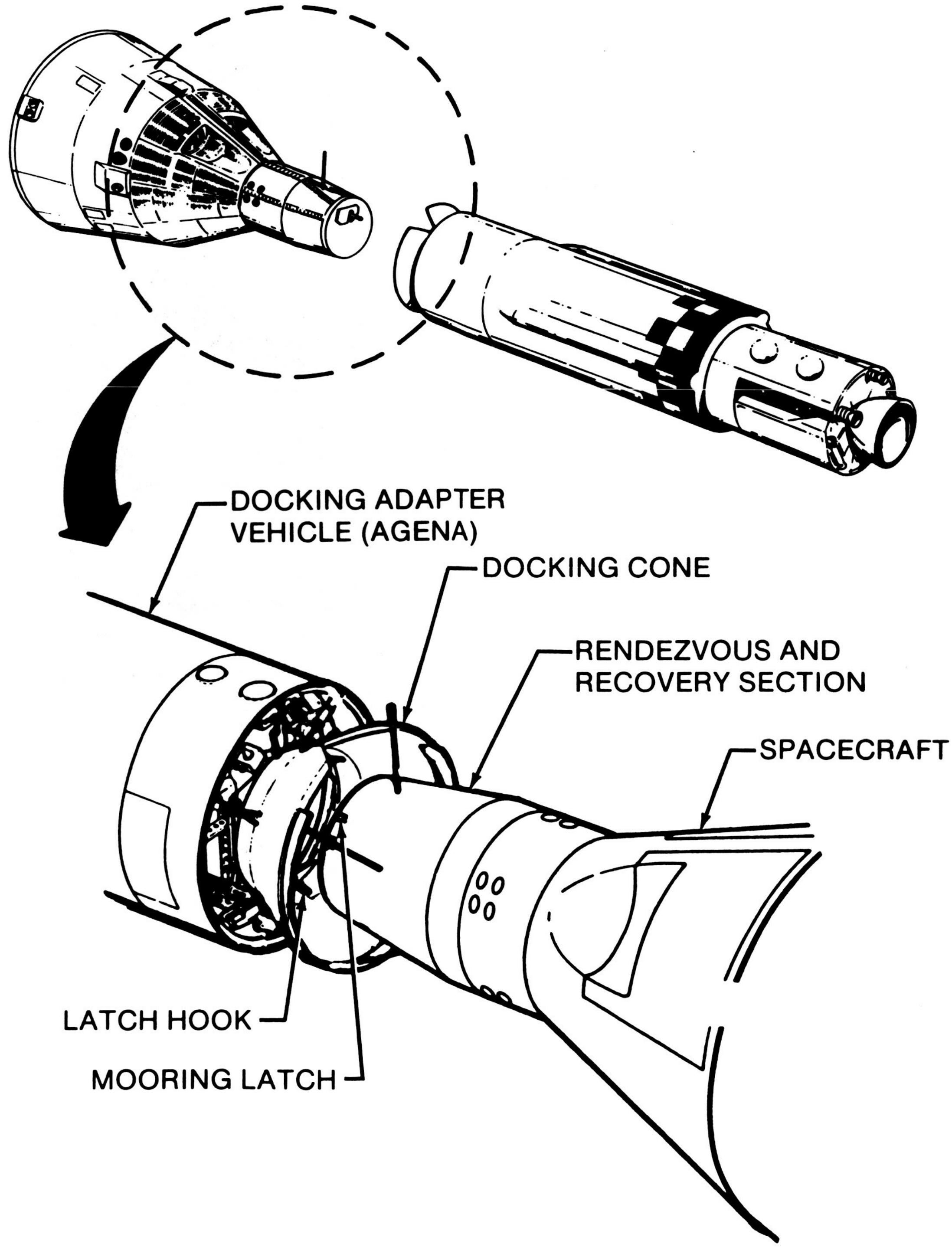

Figure 1. Gemini docking system.

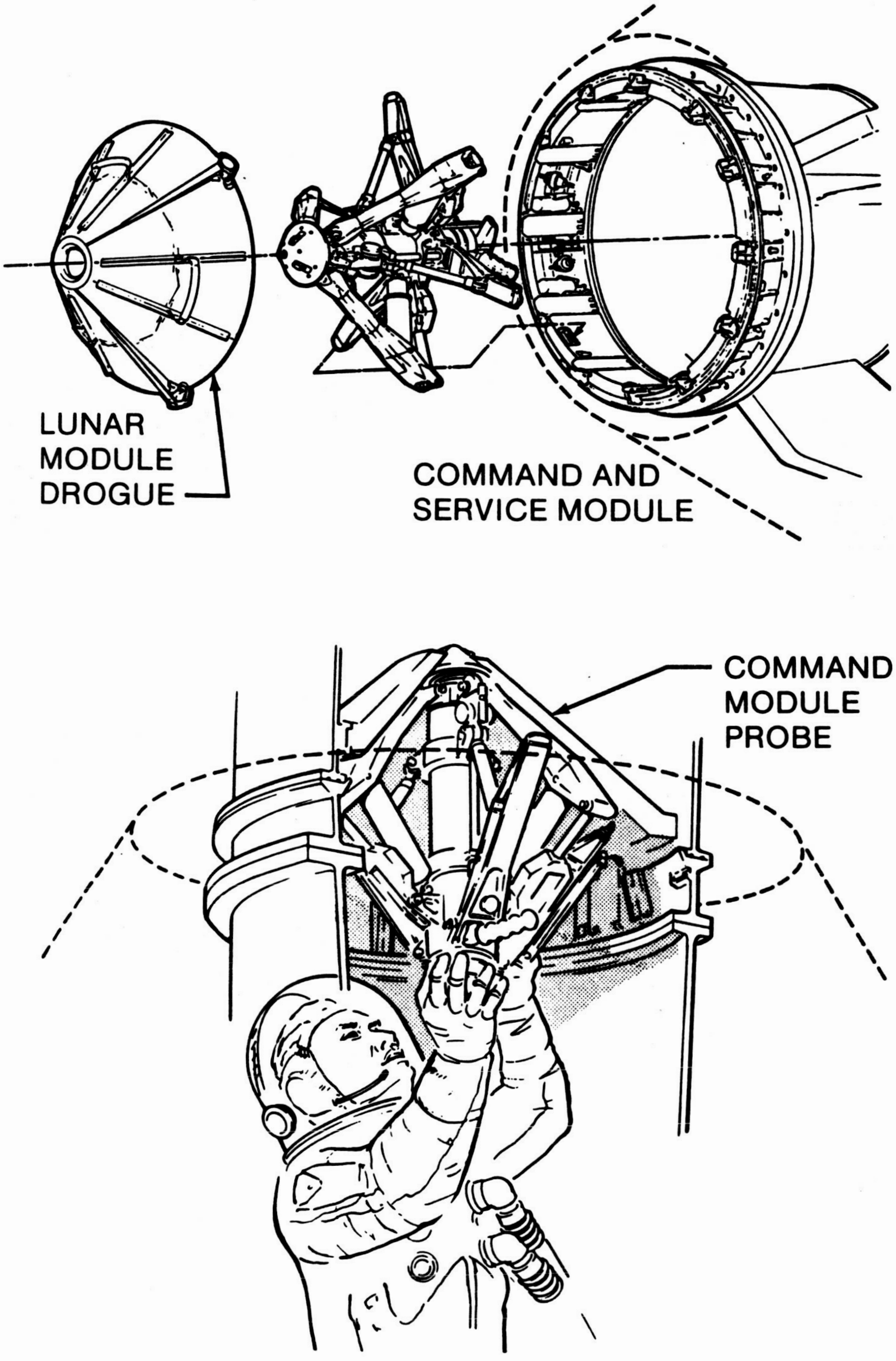

Figure 2. Apollo docking system.

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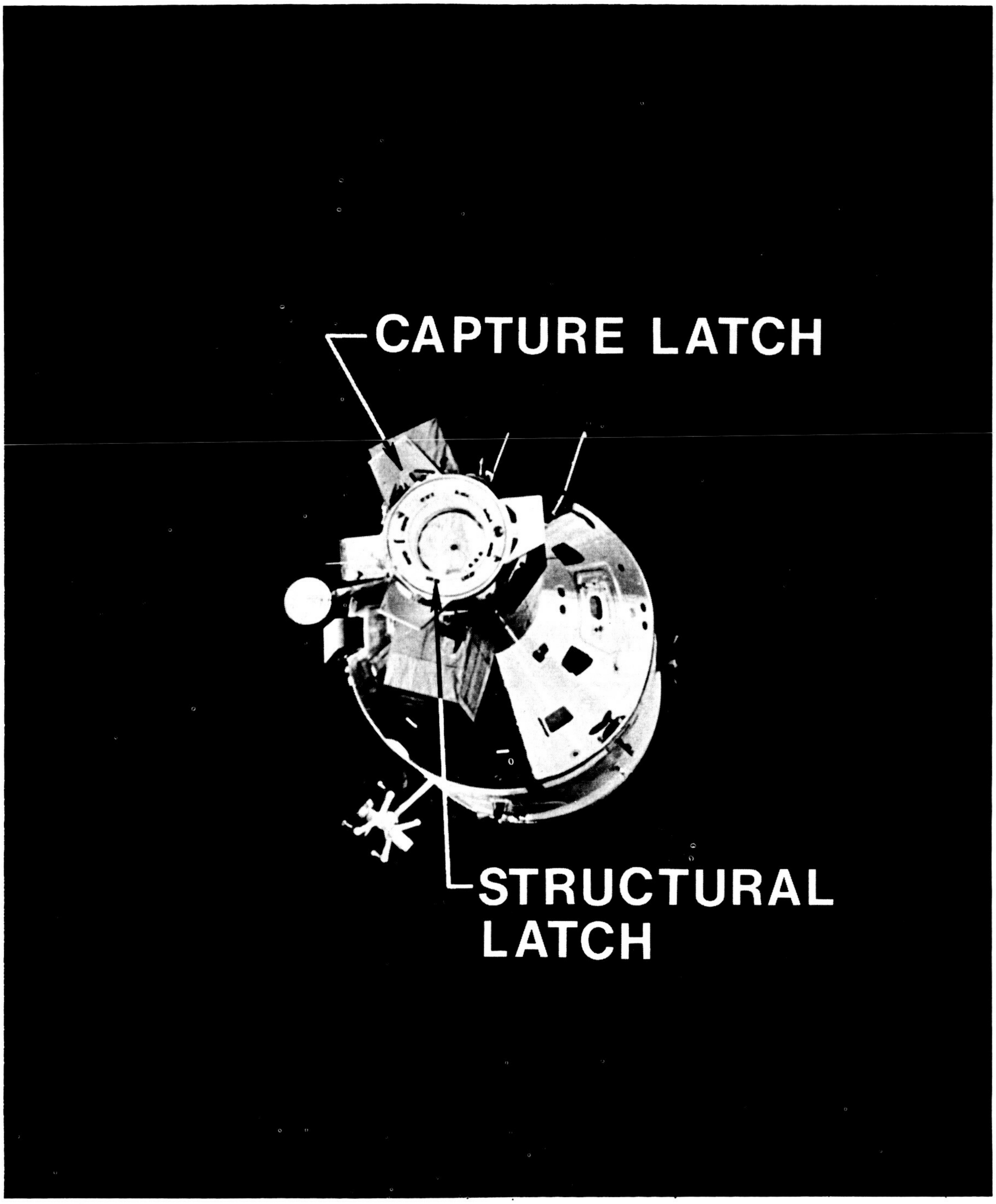

Figure 3. ASTP docking system.

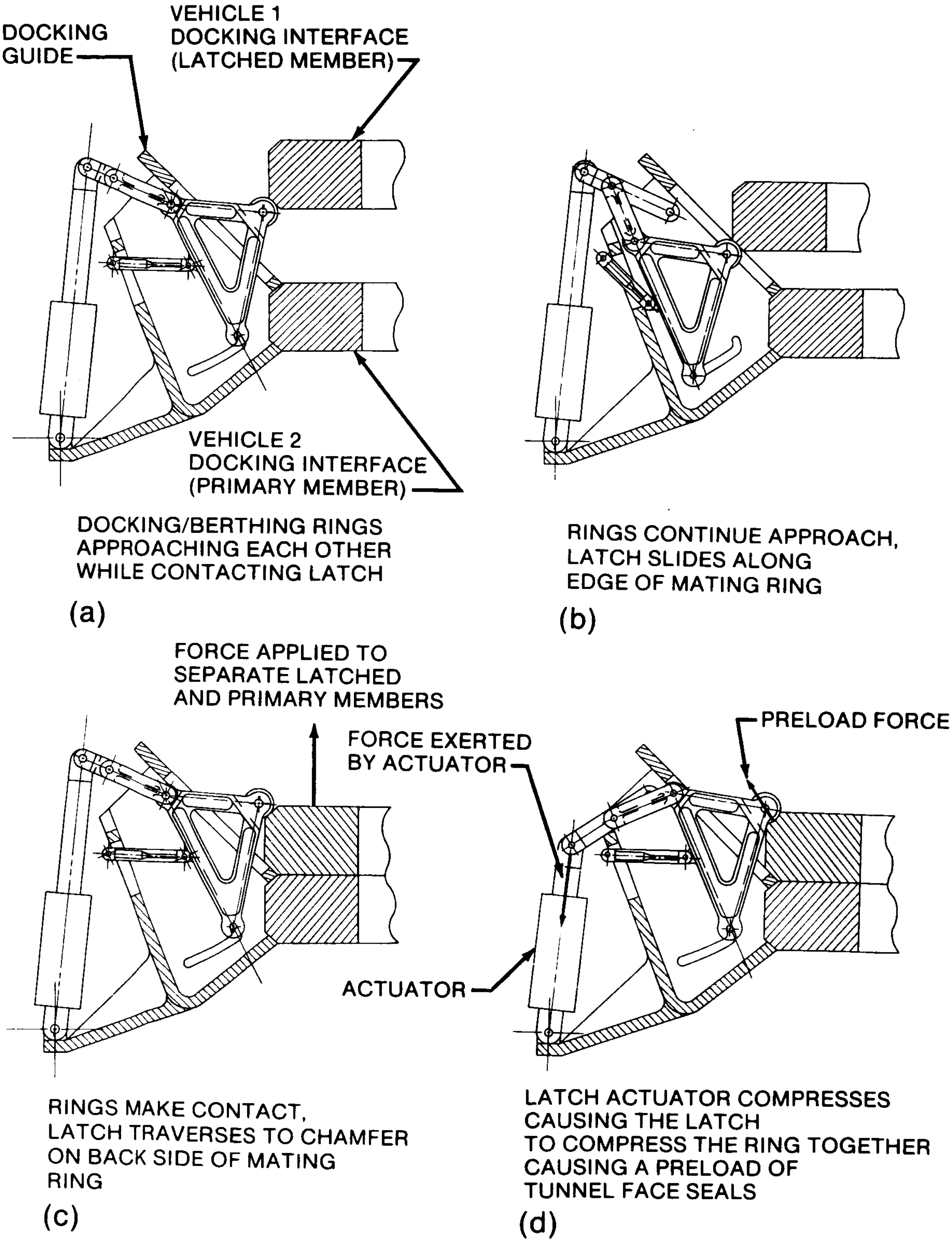

Figure 4. Functional sequence of preloadable vector sensitive latch during docking. (a) Docking/berthing. (b) Latch being compressed. (c) Latched. (d) Preload.

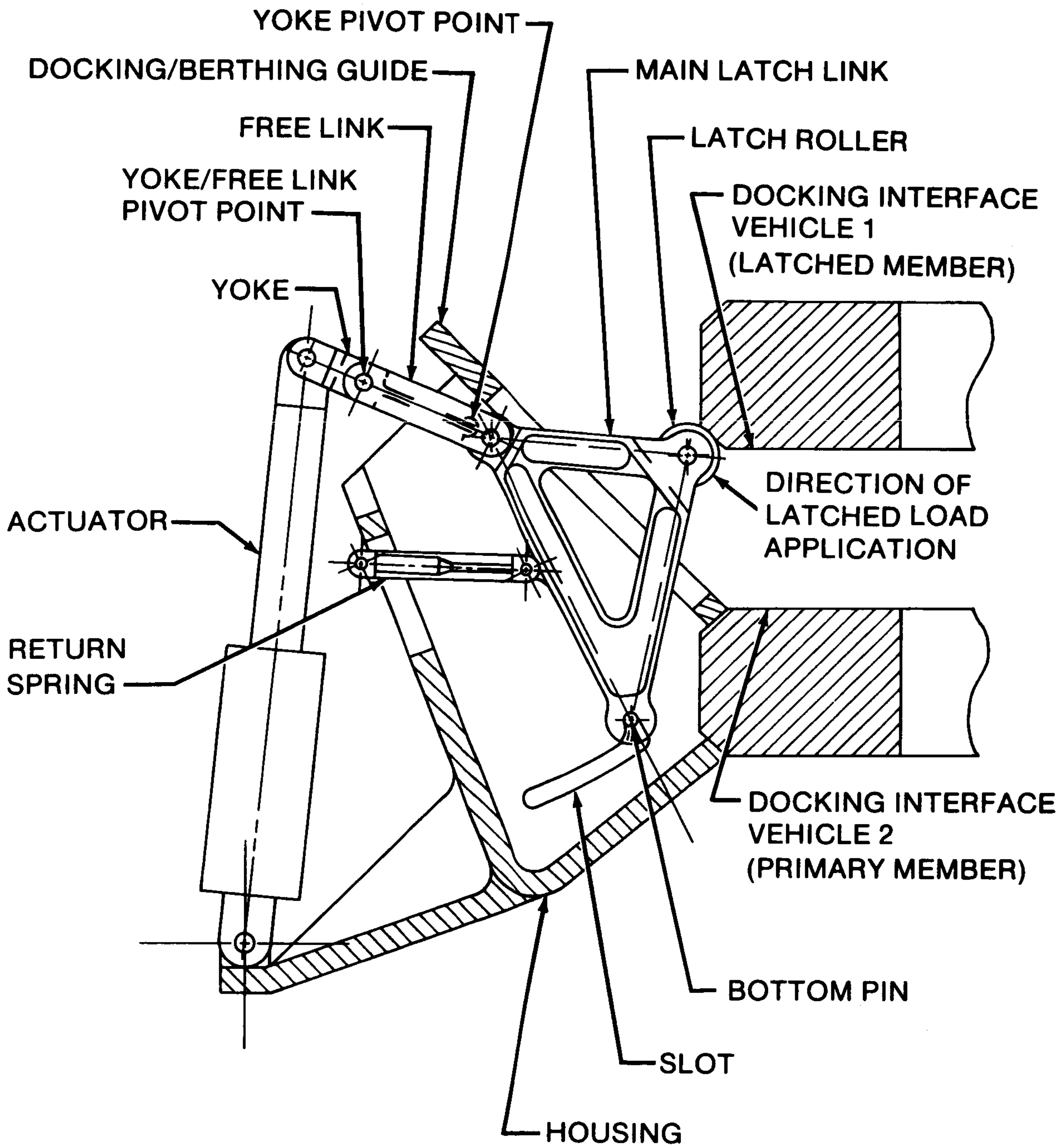

Figure 5. Latch components.

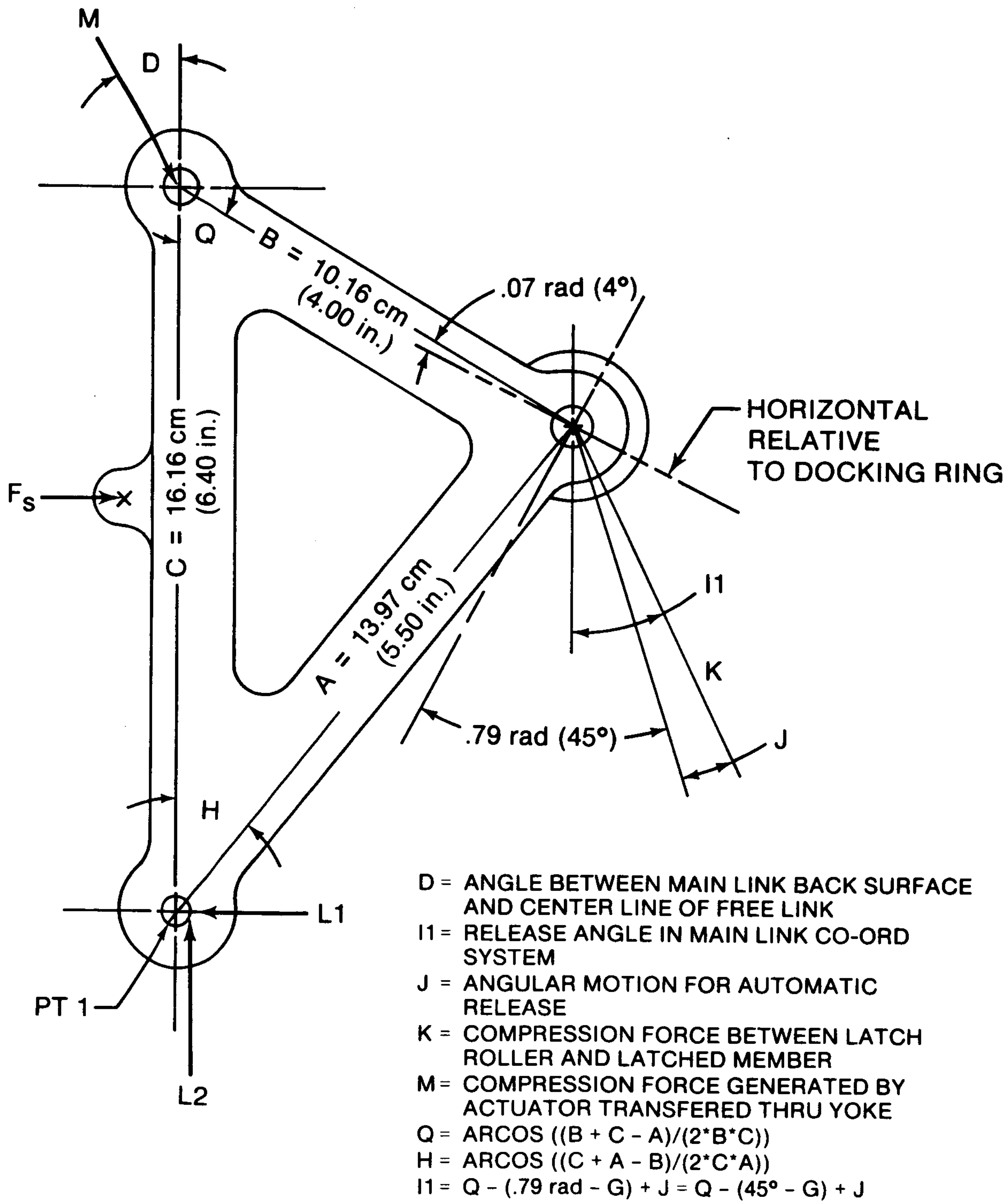

Figure 6. Latch main link.

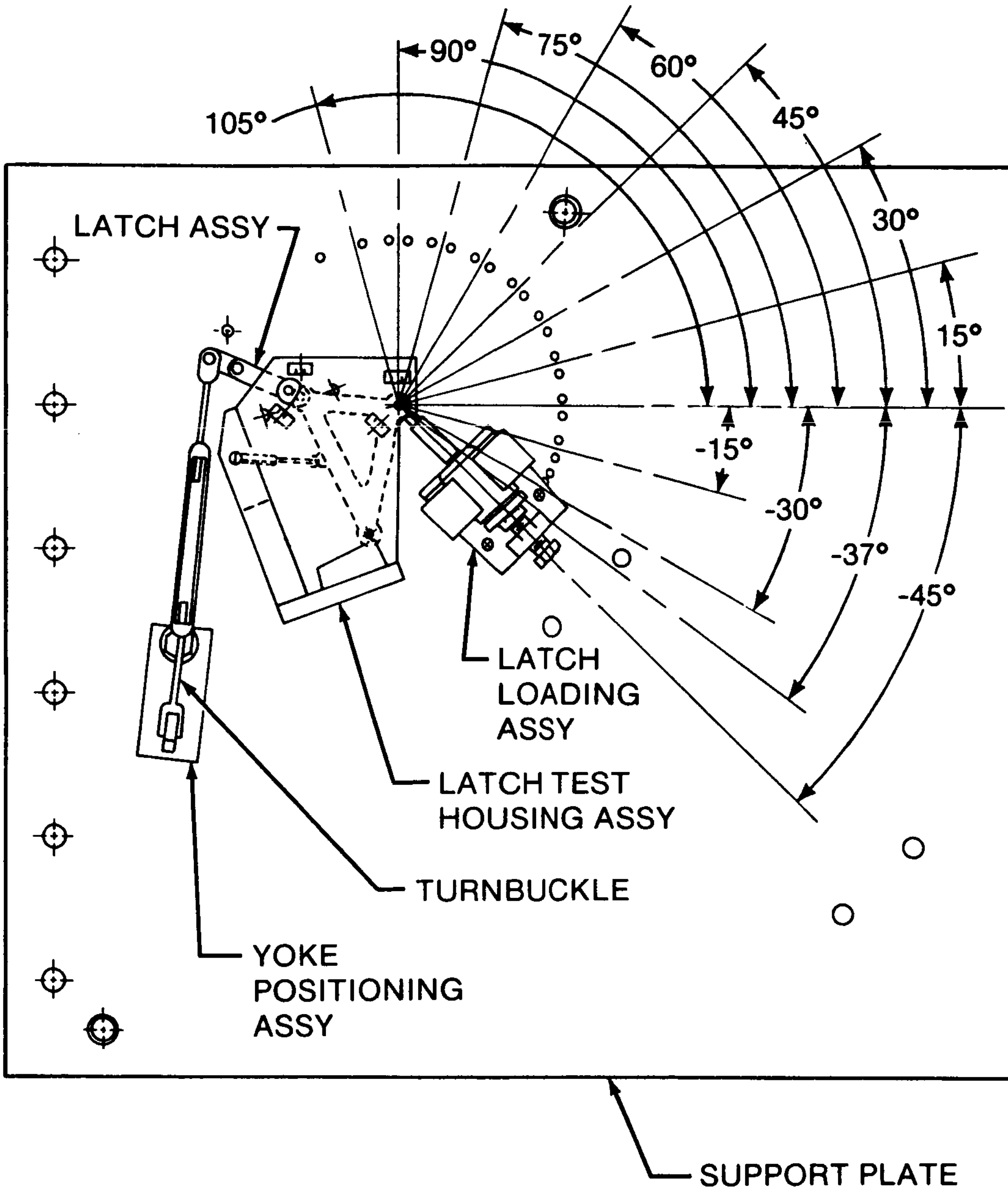

Figure 7. Yoke release position, latch loading.